Effect of Temperature and Host on Development of *Brachycaudus schwartzi* (Homoptera: Aphididae)

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ABSTRACT Populations of *Brachycaudus schwartzi* (Börner) were found on peach and nectarine (*Prunus persica* Siebold & Zuccarini) trees in Parlier, CA, in summer 2000. To determine if this aphid could be a pest of *P. persica*, a nine-variety host range test was conducted using a no-choice arena and temperature-dependent development studies of the aphid at 15, 20, 22.5, 25, 27.5, 30, and 32.5°C. Nectarine variety Mayfire ($r_m = 0.286$) and Queencrest peach ($r_m = 0.283$) were found to be the best hosts followed by Mayglo nectarine ($r_m = 0.253$). Mayfire was, therefore, selected as the host plant for the colony and for the temperature development studies. Detached shoot terminals of Mayfire were maintained on Hoagland's solution and placed in small cages in growth chambers. One adult aphid was introduced onto each flush and development of aphid offspring was monitored daily. The shortest developmental time from first instar to adult aphid was 6.9 d at 25°C and the longest was 19.9 d at 15°C. Adult longevity was 38.5 d at 15°C and the highest offspring per female was 46.4 nymphs per female at 20°C. The intrinsic rate of increase (r_m) rose sharply from 15°C (0.109 nymphs/♂/d) to a maximum at 25°C ($r_m = 0.286$), and then fell sharply at 27.5°C with high mortality at 30°C and above. The lower threshold for development was 10.04°C. Overall, the data indicate that *B. schwartzi* does better at cooler temperatures and that early season peach or nectarine varieties may be susceptible to damage by this aphid.

KEY WORDS peach aphids, life table, host range

PEACHES AND NECTARINES (*Prunus persica* Siebold & Zuccarini) are grown in 17 counties in California on ≈41,562 h and in 2000 produced more than 1.15 million tons valued at more than U.S. $357.87 million (USDA NASS 2000). According to these statistics, California growers produced 75.6% of the nation's peach and nectarine crop on 53.7% of the total national acreage. In July 2000, we found populations of *Brachycaudus schwartzi* (Börner) on peach and nectarine trees in commercial orchards in Parlier, CA. According to Stoetzel and Miller (1998), the distribution of *B. schwartzi* in North America is limited to California. Although a number of aphid species occur on stone fruits, they are generally pests during spring when large populations can cause leaf distortion and stunt shoot growth (Barnett and Rice 1989, Strand 1999). Honeydew produced by aphids can also cause fruit cracking and splitting as well as sooty mold growth that blackens leaves and fruit. Feeding by *B. schwartzi* is reported to cause severe curling and disfiguration to peach leaves (Blackman and Eastop 1984). It is unknown if this aphid can transmit the plum pox virus.

To date, there are only a few reports on the biology of peach aphids, and there are no reports on temperature-dependent development, fecundity, or longevity of *B. schwartzi.*

Fecundity of the aphid on different peach and nectarine varieties and a life table study was developed using temperature-dependent growth curves to determine the aphid's potential as a pest.

Materials and Methods

Aphid Colony. *Brachycaudus schwartzi* was obtained from a natural infestation found on peach at the United States Department of Agriculture, Agricultural Research Service, San Joaquin Valley Agricultural Sciences Center, Parlier, CA. Aphid identification was confirmed by M. Stoetzel (USDA, ARS, Beltsville, MD).

Host Plant Testing. Nine commercial peach and nectarine varieties listed in Table 1 were tested to determine the host range of *B. schwartzi*. To overcome the preconditioning effect of the prior host, aphids were reared for two generations on each variety before starting the experiment (Kindlmann and Dixon 1989).

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Table 1. Effect of host variety on development of _Brachycaudus schwartzi_

Variety	Type	Fruit maturation		Developmental data				Life table indices		
			n	Nymphal mortality rate, %	Developmental time, d	No. offspring/♀	n	Intrinsic rate of increase (r_m) (♀♀/♀/day)	Reproduction rate (R_o) (♀♀/♀)	Generation time, d
Mayfire	N	Mid-May	49	10.2	6.9 ± 0.12a	37.3 ± 2.70a	43	0.286 ± 0.0093a	32.93	13.97
Queencrest	P	Early May	33	3.0	6.9 ± 0.19a	31.9 ± 3.95a	32	0.283 ± 0.0103a	30.94	13.82
Mayglo	N	Late May	33	15.2	7.0 ± 0.22a	22.8 ± 3.02b	33	0.253 ± 0.0111ab	21.03	14.07
O'Henry	P	Mid-August	32	6.3	7.5 ± 0.25ab	15.7 ± 1.75bc	32	0.222 ± 0.0112bc	14.69	13.72
Crimson Lady	P	Late May–Early June	35	11.4	8.3 ± 0.24c	18.9 ± 2.22bc	36	0.206 ± 0.0116cd	17.08	15.93
September Free	N	Mid-September	30	10.0	8.2 ± 0.23c	17.6 ± 2.05bc	30	0.204 ± 0.0095cd	15.87	14.83
Red Diamond	N	Early July	33	24.2	8.5 ± 0.32c	17.4 ± 1.98bc	34	0.192 ± 0.0124cd	13.29	14.96
Fairtime	P	Mid-September	32	15.6	8.1 ± 0.21bc	13.6 ± 2.06c	32	0.189 ± 0.0143d	11.50	13.91
Summerfire	N	Late August	24	37.5	9.6 ± 0.39d	14.0 ± 3.41c	24	0.142 ± 0.0185e	8.75	17.03
		F			13.03	10.63		15.16		
		df			8,250	8,241		8,287		
		P			0.0001	0.0001		0.0001		

Means in columns followed by same letter are not significant ($P > 0.05$, GLM) in ANOVA (LSD). N, nectarine; P, peach.

Aphid Rearing. The aphid was reared on detached shoots of Mayfire nectarine at 25 ± 1°C, 75 ± 10% RH, and a photoperiod of 16:8 (L:D) h artificial light of ≈330 foot-candles (3,550 lux) in an environmental chamber from two to four generations before the experiments began. The shoots were maintained in orchid tubes (small plastic tubes), 1.5 by 9 cm (diameter by height), filled with a modified Hoagland solution containing the following nutrients per liter of distilled water: 0.69 g Ca (NO$_3$)$_2$ · 4 H$_2$O; 0.29 g KNO$_3$; 0.08 g KH$_2$PO$_4$, 0.29 g MgSO$_4$ · 7H$_2$O; 0.31 ml FeCl$_3$ · 6H$_2$O; 0.04 g Na$_2$ EDTA · 4H$_2$O; 0.0072 g H$_3$BO$_3$; 0.0046 g MnCl$_2$ · 4H$_2$O; 0.0003 g ZnCl$_2$; 0.0001 g CuCl$_2$ · 2H$_2$O; 0.00008 g Na$_2$MoO$_4$ · 2H$_2$O; pH 6.2 (Hoagland and Arnon 1950). Aphids were then transferred to the shoot which was then covered with a transparent plastic cage, 15 by 5 cm (length by diameter), with a polyester organdy top. Shoots were cut directly from the tree to maintain a fresh supply of host material and the host material was changed as necessary.

Development and Survivorship of Nymphs. Apterous adult aphids from the colony were transferred onto Mayfire terminals maintained as above. Nymphs born within 24 h were transferred individually by camel's-hair brush and placed onto a single Mayfire shoot and placed in environmental chambers at 15, 20, 22.5, 25, 27.5, 30, 32.5, and 35 ± 1°C at a humidity and photoperiod as mentioned above. The aphids were checked daily for exuviae and survivorship at all temperature regimes. Aphids were transferred to new shoots every fourth day until the death of the test aphids.

Adult Longevity and Reproduction. When the test aphid became reproductively mature, the number of offspring and mortality were determined daily. Nymphs were removed from the test arena after counting and these observations continued until the mature aphid died.

Data Analysis and Evaluation. The data collected were analyzed per temperature by analysis of variance (ANOVA) and differences determined by the least significant difference (LSD) test. Statistical tests were performed using PROC GLM (SAS Institute 1990). The relationship between temperature (T) and the rate of development (r_T) was described by a linear regression model where $r_T = a + bT$ following the method of Campbell et al. (1974). The thermal threshold (t) and the thermal constant (K) were estimated by the equation $t = -a/b$ and $K = 1/b$, where a and b are estimated parameters and the data are expressed as degree-days (Campbell et al. 1974). Development that occurred at temperatures >25°C was outside the linear segment of the growth curve and were excluded from the linear analysis.

Life table construction was done using age specific fecundity (m_x) and survival rates (l_x) for each age interval (x) per day (Andrewartha and Birch 1954) and the intrinsic rate of increase (r_m) was assessed by the equation:

$$1 = \sum e^{-rmx} l_x m_x,$$

where r_m was calculated for the original data (r_{all}). The differences in r_m values were tested for significance by estimating the variance using the jack knife method (Meyer et al. 1986). The jack knife pseudo value r_j was computed for the n samples using the following equation:

$$r_j = n r_{all} - (n - 1) r_i.$$

The mean values of (n − 1) jack knife pseudo-values for each treatment were subjected to ANOVA. The differences between the mean values of jack knife pseudo-values were analyzed by LSD test. Statistical tests was performed using PROC GLM (SAS Institute 1990).

Results

Host Plants. Mayfire nectarine and Queencrest peach were the best hosts of _B. schwartzi_ with the shortest development time (6.9 d) and highest number of offspring (37.3 and 31.9, respectively) ($P \geq$ 0.05). The highest daily rates of progeny (r_m) pro-
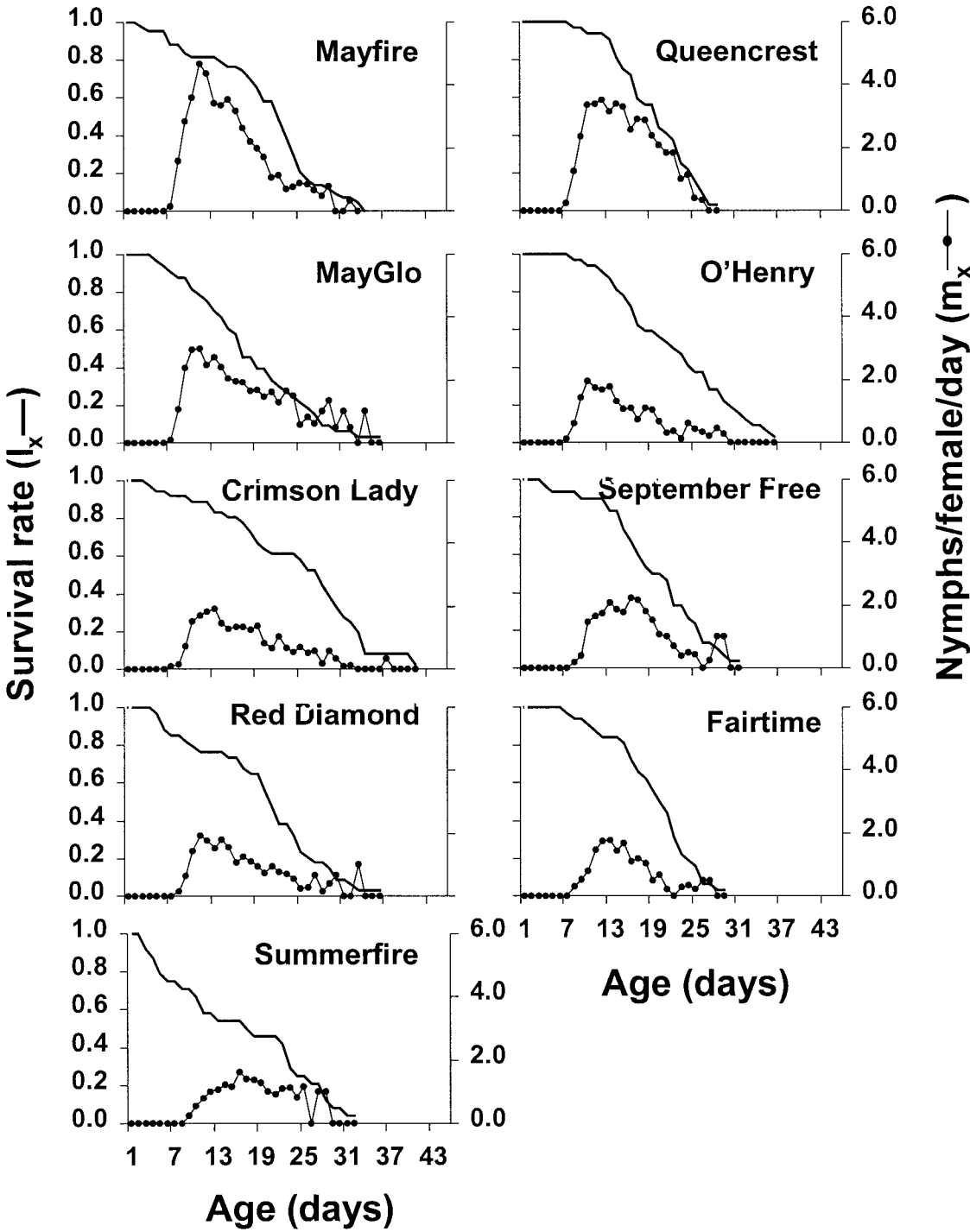
Fig. 1. Survival rate (l_x) and fecundity (m_x) of *Brachycaudus schwartzi* on different varieties of *Prunus persica* at 25°C.

duction were 0.286 and 0.283 for Mayfire and Queencrest, respectively, followed by Mayglo (0.253) and O'Henry (0.222) (Table 1; Fig. 1). Crimson Lady, September Free, and Red Diamond were acceptable hosts but the aphid had lower r_m levels on these hosts. Aphids on Fairtime and Summerfire had the lowest r_m and R_o ($P \geq 0.05$) but these hosts were not considered resistant or tolerant.

Table 2. Effect of temperature on development of *Brachycaudus schwartzi*

Temp, °C		Developmental data					Life table indices		
	n	Nymphal mortality, %	Developmental time, d	Longevity	No. offspring/♀	n	Intrinsic rate of increase (r_m) (♀♀/♀/day)	Reproductive rate (R_o) (♀♀/♀)	Generation time, d
15.0	48	12.5	19.9 ± 0.29a	38.5 ± 2.93a	44.0 ± 3.83ab	47	0.109 ± 0.0036c	37.52	38.55
20.0	57	1.8	11.0 ± 0.08b	23.7 ± 1.68b	46.4 ± 3.58a	48	0.199 ± 0.0043b	43.50	22.86
22.5	51	7.8	7.9 ± 0.17d	15.7 ± 1.33c	36.9 ± 3.08b	47	0.241 ± 0.0104ab	28.66	16.00
25.0	49	10.2	6.9 ± 0.12e	15.2 ± 0.87c	37.3 ± 2.70b	43	0.286 ± 0.0093a	32.93	13.97
27.5	47	19.2	7.4 ± 0.17de	8.7 ± 0.79d	2.3 ± 0.44c	42	0.058 ± 0.0205d	1.79	10.84
30.0	79	28.0	7.6 ± 0.25de	2.3 ± 0.72e	2.3 ± 0.72c	50	0.053 ± 0.0344d	1.64	10.37
32.5	50	88.0	9.5 ± 0.22c	1.5 ± 0.34e	—	—	—	—	—
35.0	70	100.0	—	—	—	—	—	—	—
		F	616.93	50.25	46.29		28.98		
		df	6,262	6,235	5,227		5,271		
		P	0.0001	0.0001	0.0001		0.0001		

Means in columns followed by same letter are not significant ($P > 0.05$, GLM) in ANOVA (LSD).

Temperature Dependent Development. Nymphal development time was evaluated on Mayfire nectarine shoots. Development time from first instar to adult aphid decreased from 19.9 d at 15°C to 6.9 d at 25°C and then began to increase from 27.5°C (Table 2). Nymphal mortality was lowest at 20 (1.8%) and 22.5°C (7.8%), and increased to 28% at 30°C. Mortality at 35°C was 100% and was considered as the upper threshold, therefore, the data were excluded from the analysis. Aphid fecundity was highest at 20°C (R_o = 43.5), but the aphid also produced high numbers of offspring at 15, 22.5, and 25°C. At temperatures ≥ 27.5°C, there was a sharp decrease of fecundity (Fig. 2). Adult longevity declined from 38.5 d at 15°C to 1.5 d at 32.5°C (Table 2, $P \geq 0.05$). Survival rates (l_x) of *B. schwartzi* decreased more sharply at 22.5 and 25°C than at 15 and 20°C (Fig. 2). Nymphal production (m_x) increased from 2.1 on day 36 at 15°C to a maximum of 4.7 on day 11 at 25°C, then declined to 0.53 and lower on day 10 at ≥ 27.5°C (Fig. 2). Although a few nymphs completed development at 32.5°C, no progeny were obtained (Fig. 2).

Linear regression of development between 15 and 25°C resulted in an $r_T = -0.0974 + 0.0097T$ (R^2 = 0.9869; F = 150.3; P = 0.001) (Fig. 3). The theoretical development threshold was extrapolated as 10°C. Based on this, 103.1 d degrees were required for a first-instar nymph to become an adult.

Life Table Indices. The intrinsic rate of increase (r_m) was highest at 25°C (r_m = 0.286 nymphs/adult/d, $P \geq 0.05$) followed by 22.5°C (r_m = 0.241) and 20°C (r_m = 0.199) ($P \geq 0.05$) (Table 2; Fig. 2). The reproductive rate was highest at 20°C (43.5 nymphs/adult), followed by that at 15, 25, and 22.5°C. The reproductive rate at temperatures ≥27.5°C was virtually nil. The generation time was shortest at the warmest temperatures, but optimum temperatures were between 22.5 and 25°C.

Discussion

In host range tests, *B. schwartzi* development and fecundity was best on Mayfire and Queencrest and, to a lesser degree, Mayglo. These are considered early season varieties. Whether the host suitability is attributed to the plant's nitrogen level, as has been shown to be the case for some other aphids, is unknown. The aphid performed worst on late season varieties, such as Fairtime and Summerfire. However, further research must be performed to elucidate the nature of host suitability.

Dixon (1998) states that an aphid species typically has a limited range of hosts, food quality, and temperature over which it increases. In our studies, the intrinsic rate of increase for *B. schwartzi* reached a peak at 25°C, and at temperatures ≥27°C, it rapidly declined. All of the aphid's life history parameters were optimum at 22.5–25°C. These results are similar to those reported for *Brachycaudus rumexicolens* (Patch) (Scott and Yeoh 1999), *Macrosiphum euphorbiae* (Thomas) (Barlow 1962), *Acyrthosiphon kondoi* Shinji (Rohitha and Penman 1983), and *Rhopalosiphum nymphaeae* (L.) (Ballou et al. 1986). In contrast, some aphids perform well at warm temperatures. For example, the upper development threshold for *Aphis spiraecola* Patch on *Polyscias crispata* (Bull) Merr. was 32–35°C (Wang and Tsai 2000) and for *Aphis gossypii* Glover on cotton the upper development threshold was 32–35°C (Kersting et al. 1999).

We calculated the theoretical development threshold for *B. schwartzi* to be 10°C and 103 d degrees were required for a first instar nymph to reach maturity. In comparison, the thermal threshold for *B. rumexicolens* was calculated to be 6.5°C on *Emex australis* Steinheil, which is a winter and spring host of this aphid (Scott and Yeoh 1999). However, at warmer temperatures, the population growth curve of *B. schwartzi* showed similar deleterious effects as that for *B. rumexicolens*. Other aphids commonly found on peach, such as *A. spiraecola*, have a thermal threshold of 2.3°C (Wang and Tsai, 2000), whereas that of *A. gossypii* was 6.2°C (Kersting et al. 1999). Although we did not determine how *B. schwartzi* overwinters in our area, our temperature studies point to the egg as the overwintering stage as has been reported for *Brachycaudus helichrysi* (Kaltenbach) in California (Madsen and Bailey 1958).
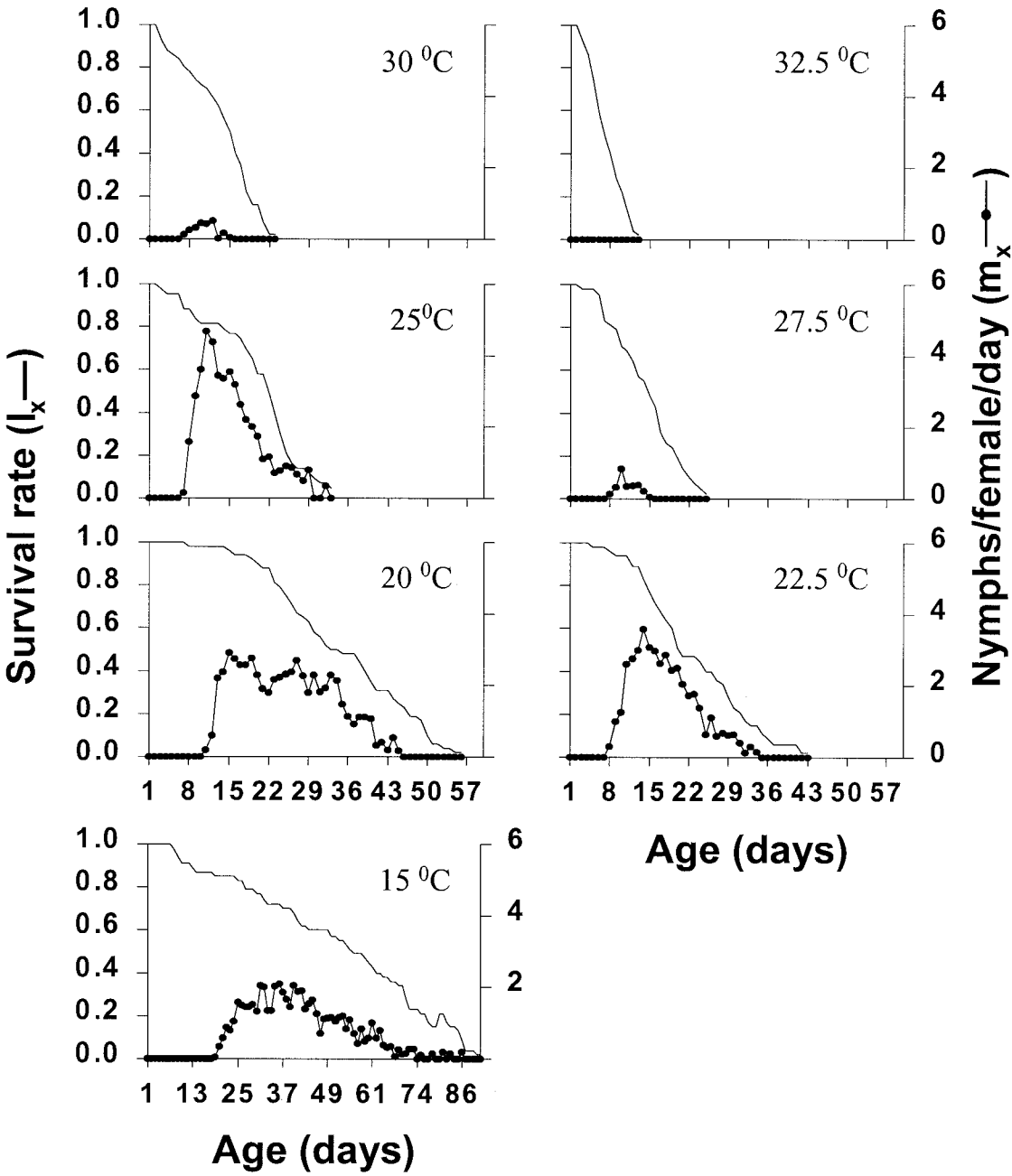
Fig. 2. Survival rate (l_x) and fecundity (m_x) of *Brachycaudus schwartzi* at different constant temperatures.

Our data suggest that in a temperature region such as the San Joaquin Valley, *B. schwartzi* may do well under springtime conditions. Further, since early season varieties such as Mayfire and Queencrest were good hosts, *B. schwartzi* has greatest pest potential on early season varieties when temperatures are most favorable for aphid development.
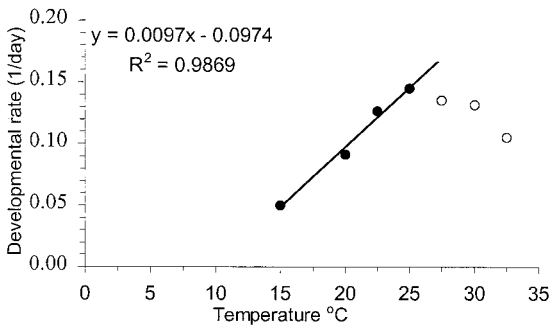
Fig. 3. Regression analysis of *Brachycaudus schwartzi* development rate at different constant temperatures. Open circles indicate data points not in the linear portion of the development curve and excluded from the analysis.

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